Status of the subtropical scleractinian coral communities in the turbid environment of Moreton Bay, southeast Queensland

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ABSTRACT

The subtropical scleractinian coral communities of Moreton Bay exist in a marginal environment for reef corals. Moreton Bay is a shallow marine bay that is strongly influenced by adjacent rivers that discharge large volumes of freshwater, sediment and pollutants during periodic flood events. The 1974 flood caused catastrophic coral mortality at many sites in the western region of the Bay, while the 1956 flood caused heavy coral mortality on reefs around Peel Island. This paper provides a synthesis of the results of more recent quantitative surveys of the coral fauna and reefs during 1991, 1994, 2002 and 2003 to determine the status of the coral communities in Moreton Bay. Coral species richness and mean percentage coral cover increased at all sites surveyed in Moreton Bay after the 1974 flood, except along the eastern side of Green Island where coral cover remains less than 13% of the pre-flood cover. Mean live coral cover was highest at Myora Reef with 42–66%, and this is the only site within Moreton Bay that is dominated by *Acropora* corals. Mean coral cover at other sites ranged from 1–40% and the coral communities are dominated by massive corals, particularly brain corals from the Family Faviidae. A total of 63 scleractinian reef coral species from 21 genera from 10 families have now been recorded in Moreton Bay, which represents a substantial increase in coral species richness compared to the 18 coral species recorded prior to 1974. The re-zoning of the Moreton Bay Marine Park in 2008 provides an important opportunity to increase the protection of the unique coral communities in Moreton Bay. Based on these reef surveys we recommend increased protection for the reefs at southeast Peel Island and Goat Island because these sites contain high coral species richness, and the eastern reefs at Green Island because of the presence of large colonies of *Psammocora superficialis* dated at over 200 years old. ❑ *subtropical corals, high turbidity, flood impacts, coral resilience, marine park.*

Coral reefs are best developed in tropical regions where warm, clear and shallow seas provide abundant light, oceanic salinity and high aragonite saturation conditions suitable for reef-building by hermatypic scleractinian corals (Veron 2000; Harrison & Booth 2007). Substantial subtropical coral reefs also occur in some regions between latitudes 31°33′S and 33°48′N where warm tropical currents provide suitable conditions for reef accretion (e.g. Harriott *et al.* 1994, 1995; Veron 2000; Yamano *et al.* 2001; Harrison & Booth 2007). Where

Table 1. Mean percentage cover of scleractinian corals in Moreton Bay recorded by Lovell (1975) before the 1974 flood and the estimated percentage coral mortality after the flood. Mean percentage coral cover (± standard error) recorded after the flood by Lovell (1989), Harrison *et al.* (1991), Maguire (1994), the Environmental Protection Agency (EPA) (2004), and in 2002–03. - = no data.

Site	Pre-flood	Post-flood	Mortality	Source
Mud Is. SW	1	-	100	Lovell (1975)
Mud Is. S-SE	-	1.2 ± 0.3	-	2002
St Helena Is. S	1	-	100	Lovell (1975)
St Helena Is. S	-	13.8 ± 11	-	EPA (2004)
Green Is. W	4	-	100	Lovell (1975)
Green Is. W	-	0.8 ± 0.2	-	Harrison *et al.* (1991)
Green Is. W	-	8.9 ± 3.7	-	EPA (2004)
Green Is. E	36.2	-	70-90	Lovell (1975)
Green Is. E	-	1.8 ± 0.7	-	Harrison *et al.* (1991)
Green Is. E	-	4.6 ± 1.1	-	2002
Wellington Pt.	1.4	-	100	Lovell (1975)
Wellington Pt.	-	1.3 ± 0.8	-	Harrison *et al.* (1991)
Wellington Pt.	-	2.8 ± 1.6	-	2003
Empire Pt	2.8	1.2 ± 0.4	100	Lovell (1975)
Empite Pt.	-	1.2 ± 0.4	-	Harrison *et al.* (1991)
Empire Pt.	-	4.8 ± 0.9	-	2003
Coochiemudlo Is. N	1	-	100	Lovell (1975)
Coochiemudlo Is. N	-	6.1 ± 8.6	-	EPA (2004)
Peel Is. N-NE	12.3	-	0	Lovell (1975)
Peel Is. NE	-	17.9 ± 5.3	-	Harrison *et al.* (1991)
Peel Is. NE	-	36.6 ± 8.7	-	Maguire (1994)
Peel Is. NE		2.6 ± 1.4	-	Maguire (1994)
Peel Is. NW	-	17.9 ± 6.3	-	Maguire (1994)
Peel Is. N		9.8 ± 1.5	-	2002
Peel Is. SE	1	-	10	Lovell (1975)
Peel Is. SE	-	2.3 ± 0.7	-	Harrison *et al.* (1991)
Peel Is. SE	-	18.3 ± 8.6	-	Maguire (1994)
Peel Is. SE	-	6.9 ± 1.1	-	2002
Peel Is. SW	20.9	1.6	100	Lovell (1975)
Peel Is. SW	-	4.3 ± 1.3	-	Maguire (1994)
Peel Is. W	-	40.7 ± 3.7	-	EPA (2004)
Myora R.	1	-	0	Lovell (1975)
Myora R.	-	66.67 ± 9.8	-	EPA (2004)
Myora R.	-	42.3 ± 5.1	-	Harrison *et al.* (1991)
Myora R.	-	15 ± 4.9	-	2002
Bird and Goat Is. W	15.6	-	20	Lovell (1975)
Bird and Goat Is. E	5	-	10	Lovell (1975)
Bird and Goat Is. E	-	11.4 ± 3.6	-	Maguire (1994)

temperature and other environmental conditions become marginal or highly fluctuating for coral reef building, conditions have been described as marginal (sensu Kleypas *et al.* 1999) and non-reef building (Perry & Larcombe 2003). Some of these marginal coral communities have relatively high species diversity and coral cover (Harrison *et al.* 1991, 1998; Harriott *et al.* 1994, 1995; Riegl 1999; Perry & Larcombe 2003; Ferreira 2003). Moreton Bay is considered a marginal environment for scleractinian corals because of high turbidity and reduced light (Kleypas *et al.* 1999), however, some unique and thriving coral communities do exist in Moreton Bay and at Flinders Reef, to the north of Moreton Bay, where 40 and 119 coral species have been recorded respectively (Harrison *et al.* 1991, 1995, 1998).

Previous studies on the coral communities of Moreton Bay have indicated that floods are a major factor influencing their structure and ecology (Slack-Smith 1960; Lovell 1975, 1989). The impact of floods on the scleractinian corals of Moreton Bay was first documented by Slack-Smith (1960) who reported coral mortality between 0–10% and 100% on the northern and eastern reef flat of Peel Island after a heavy rainfall during the summer of 1956. During this event, *Favia speciosa* was the species mostly affected. Lovell (1975) also reported coral mortality up to 100% at most sites during the severe 1974 flood (Table 1). *Acropora*, *Goniopora*, *Turbinaria*, *Favia* and *Psammocora* present in Moreton Bay are, in decreasing order, negatively affected by flooding (Lovell 1989; Johnson & Neil 1988a). The coral community on the western reef of Peel Island, where coral death was estimated at 100%, was resurveyed in 1981 to assess coral recovery and 7 species of corals were recorded, 2 more than during the pre-flood period (Lovell 1989). Subsequent surveys on the coral communities in Moreton Bay were completed by Harrison *et al.* (1991) at Wellington Point, Empire Point and Green Island, by Harrison *et al.* (1995, 1998) at Myora Reef, by Maguire (1994) at Peel and Goat Islands, and by the Ecosystem Health Monitoring Program (EHMP 2004) at St. Helena Island, Green Island and along the western side of Peel Island.

Scleractinian coral communities in the vicinity of river systems are subject to coral mortality and loss of coral cover during periodic floods that cause reduced salinity, increased sedimentation and turbidity (McLaughlin *et al.* 2003; Restrepo *et al.* 2006). Coral mortality due to reduced salinity has been previously documented (e.g. Coles & Jokiel 1992; Morberg *et al.* 1997; Perry 2003), as well as the detrimental effects of increased sedimentation (Rogers 1990; Nugues & Roberts 2003; Fabricius 2005; Sanders & Baron-Szabo 2005) and nutrients on various aspects of coral physiology (Ward & Harrison 2000; Ferrier-Pagès *et al.* 2001; Harrison & Ward 2001; Koop *et al.* 2001; Cox & Ward 2002; Cruz-Piñón *et al.* 2003). Human activities including land clearing, agriculture practices and fishing resulting from the rapidly growing population of Brisbane directly affect Moreton Bay biota (Dennison & Abal 1999). Moreover, extreme temperatures, characteristic of a shallow bay like Moreton Bay, caused coral bleaching in Moreton Bay during the summer period in 1998 (I. Tibbetts pers. comm.).

The scleractinian corals of Moreton Bay grow on a late Holocene reef of unconsolidated fossil coral rubble mixed with terrigenous sediment (reviewed by Johnson & Neil 1998b). These subtropical coral communities are dominated by massive species, in particular by Faviidae, and certain unique assemblages of tropical, subtropical and temperate scleractinian species (Lovell 1975, 1989; Harrison *et al.* 1998). Wells (1955) recorded 24 species of scleractinian corals in Moreton Bay, whereas Lovell (1975) recorded 17 species. After the 1974 flood, Lovell (1989) reported the genus *Acanthastrea* for the first time in the Bay. Harrison *et al.* (1991) completed the most thorough taxonomic survey of scleractinian corals in Moreton Bay and recorded 40 species, 6 of which were new records for the Bay (Harrison & Veron 1993).

This paper presents a synthesis of recent surveys and data on the coral communities of Moreton Bay to assess their status. Changes in percentage coral cover, species richness, evenness and diversity over the period from 16–27 years after the 1974 flood are compared. These data provide a baseline for future surveys of the health of the coral communities in Moreton Bay and highlight important issues for the management of the Moreton Bay Marine Park.

Table 2. List of scleractinian coral species recorded at Myora Reef, in Moreton Bay, during surveys. * = Lovell (1975), ** = Harrison *et al*. (1995, 1998).

Coral species	1974*	1994**	2002
ACROPORIDAE			
Acropora sp.	x		
A. digitifera		x	x
A. divaricata			x
A. glauca			x
A. hyacinthus			x
A. latistella		x	x
A. loripes			x
A. lutkeni			x
A. solitaryensis		x	x
A. valida		x	x
A. verweyi		x	
POCILLOPORIDAE			
Pocillopora damicornis			x
SIDERASTREIDAE			
Coscinarea columna	x		
Psammocora superficialis		x	x
P. contigua	x		
MERULINIDAE			
Hydnophora exesa			x
DENDROPHYLLIDAE			
Turbinaria sp.		x	
T. peltata	x	x	x
MUSSIDAE			
Acanthastrea bowerbanki			x
A. echinata		x	
A. hemprichii			x
A. hillae		x	
A. lordhowensis		x	
FAVIIDAE			
Barabattoia amicorum		x	
Cyphastrea serailia		x	x
Favia maritima			x
F. matthaii			x
F. pallida			x
F. rotumana			x
F. speciosa-favus	x	x	x
Goniastrea aspera			x
G. australensis		x	
Leptastrea purpurea			x
Montastrea annuligera			x
M. curta			x
M. magnistellata		x	

Table 2 continued...

Coral species	1974*	1994**	2002
Oulophyllia crispa		x	
Plesiastrea versipora	x	x	
PORITIDAE			
Goniopora sp.		x	
G. djiboutiensis			x
PECTINIIDAE			
Echinophyllia aspera			x
Mycedium elephantotus	x		
Total no. of species	7	19	27

MATERIALS AND METHODS

FIELD SURVEYS

Extensive surveys of the coral and benthic communities were completed on the fringing reefs of Green Island, Wellington Point, Empire Point and Peel Island in May and June 1991 (Harrison *et al*. 1991). Quantitative surveys consisted of 32 line transects aligned perpendicular to the shore covering both intertidal and subtidal areas with a total of 18.8 km of transects. A total of 960 4 m^2 quadrats were examined at 20, 25 or 50 m intervals along the transects in the intertidal areas, and at 10, 20 and 25 m intervals in the subtidal areas. The identity, number and size of all scleractinian corals within the quadrats were recorded; together with percentage cover of soft corals, mussels, algae and seagrasses, and the type of substratum was recorded. In the lower intertidal area and in the subtidal areas, the line intercept length, identity and size of corals intercepting the transect tape were recorded. The coral species present within the vicinity of each transect and in haphazard searches at each site was noted, and specimens of any coral species requiring taxonomic verification were collected using a hammer and chisel, and placed in a coded plastic bag. These samples were subsequently labelled with a coded plastic tag attached with plastic-coated wire and then bleached in a concentrated sodium hypochlorite solution to remove the polyp tissues. The skeleton samples were identified according to the taxonomic classifications of Veron and Pichon (1976, 1980, 1982), Veron *et al*. (1977), Veron & Wallace (1984) and Veron (1986), and species identifications were confirmed by C. Wallace & J. Veron (see Harrison *et al*. 1991; Harrison & Veron 1993).

Table 3. List of scleractinian coral species observed at Peel Island, in Moreton Bay, during surveys. * = Lovell (1975, 1989), ** = Harrison *et al.* (1991).

Coral species	1974, 1989*	1991**	2002
ACROPORIDAE			
Acropora digitifera	x		x
A. divaricata			x
A. glauca			x
A. solitaryensis			x
A. verweyi		x	x
POCILLOPORIDAE			
Pocillopora damicornis			x
SIDERASTREIDAE			
Coscinarea columna	x		
Psammocora superficialis		x	x
P. contigua	x	x	
FUNGIIDAE			
Cycloseris cyclolites		x	
MERULINIDAE			
Hydnophora exesa	x		
DENDROPHYLLIDAE			
Turbinaria frondens	x	x	x
T. mesenterina			x
T. peltata	x	x	x
T. patula			x
T. radicalis			x
MUSSIDAE			
Acanthastrea sp.	x		
A. bowerbanki		x	x
A. echinata		x	x
A. hemprichii			x
A. lordhowensis		x	x
Blastomussa wellsi		x	
Lobophyllia hemprichii		x	
Micromussa amakusensis		x	x
FAVIIDAE			
Barabattoia amicorum		x	x
Cyphastrea serailia	x	x	x
Favia danae		x	x
F. lizardensis		x	x
F. maritima		x	x
F. matthaii		x	x
F. pallida		x	x
F. rotumana			x
F. speciosa-favus	x	x	x
F. stelligera	x		
Favites abdita	x	x	
F. halicora	x		x
F. chinensis			x
F. complanata			x
F. flexuosa		x	x
Goniastrea aspera		x	x
G. australensis		x	x
Montastrea annuligera			x
M. curta		x	x
M. magnistellata		x	
Oulophyllia crispa		x	
Plesiastrea versipora	x	x	x
Platygyra lamellina	x	x	
PORITIDAE			
Goniopora columna			x
G. djiboutiensis		x	x
G. lobata	x		x
G. minor		x	x
G. stokesi			x
G. stutchburyi	x		x
PECTINIIDAE			
Echinophyllia aspera		x	x
Total no. of species	**16**	**32**	**42**

A total of 18 line transects were surveyed at Green Island, 14 of which continued across the subtidal region for up to 1 km for some transects. Eight intertidal and subtidal transects were surveyed at Wellington Point-Empire Point, and two at Peel Island, one transect near the Platypus wreck and the other east of the Lazaret Gutter. In addition, extensive visual surveys were done at Green and Peel Islands to identify any other coral species present (Harrison *et al.* 1991). In 1994, quantitative surveys were completed at Myora Reef at a depth of 1–3 m using five 50 m video transects oriented parallel to the reef edge within the main coral community (Harrison *et al.* 1995). Two sites were also surveyed approximately 30–50 m inshore from the main coral community using ten 1 x 1 m quadrats (Harrison *et al.* 1995, 1998).

Subsequent surveys were completed during 2002 at Mud Island, Green Island, Peel Island, and Myora Reef, and during 2003 at Wellington

Table 4. List of scleractinian coral species observed at Mud Island in Moreton Bay, during surveys. * = Lovell (1975).

Coral species	1974*	2002
ACROPORIDAE		
Acropora glauca		x
A. solitaryensis		x
DENDROPHYLLIDAE		
Turbinaria peltata	x	
FAVIIDAE		
Favia danae		x
F. maritima		x
F. matthaii		x
F. pallida		x
F. speciosa-favus	x	x
Goniastrea aspera		x
PORITIDAE		
Goniopora lobata	x	
G. stokesi		x
Total no. of species	3	9

Table 5. List of scleractinian coral species observed at Green Island, in Moreton Bay, during surveys. * = Lovell (1975), ** = Harrison *et al.* (1991).

Coral species	1974*	1991**	2002
ACROPORIDAE			
Acropora digitifera	x		
A. glauca			x
A. solitaryensis		x	
A. valida		x	
SIDERASTREIDAE			
Psammocora superficialis		x	x
P. profundacella			x
P. contigua	x	x	
PECTINIIDAE			
Mycedium elephantotus	x		
MERULINIDAE			
Hydnophora exesa	x		
DENDROPHYLLIDAE			
Turbinaria frondens	x		
T. peltata	x	x	x
MUSSIDAE			
Acanthastrea bowerbanki			x
A. echinata		x	x

Table 5 continued...

Coral species	1974*	1991**	2002
A. lordhowensis		x	x
Micromussa amakusensis		x	x
FAVIIDAE			
Barabattoia amicorum		x	
Cyphastrea serailia	x	x	x
Favia danae		x	
F. maritima		x	x
F. matthai		x	x
F. veroni			x
F. pallida		x	x
F. speciosa-favus	x	x	x
Favites abdita	x	x	x
F. halicora	x		
F. flexuosa			x
Goniastrea aspera		x	x
Plesiastrea versipora	x	x	x
Platygyra lamellina	x		
PORITIDAE			
Goniopora columna		x	x
G. djiboutiensis		x	x
G. lobata	x	x	x
G. minor		x	x
G. stokesi		x	x
G. somaliensis		x	x
G. stutchburyi	x	x	x
G. tenuidens		x	
Total no. of species	14	26	25

Point and Empire Point. At each site, 48 quadrats of 1 m² were surveyed. Eight quadrats were surveyed along each 20 m line transect with a total of three transects in shallow water (0.5–1 m below chart datum) and three transects in deeper water (2.5–3.5 m below chart datum). The transects were placed parallel to the shore and spaced 5 m from each other. Within each quadrat, each coral colony was identified to species level and its area measured to the nearest cm² by recording the longest diameter and the perpendicular diameter. At Myora Reef, six transects were surveyed within the area of the *Acropora* community, and six transects were surveyed outside the *Acropora*

Table 6. List of scleractinian coral species observed at Wellington and Empire Points, in Moreton Bay, during surveys. * = Lovell (1975), ** = Harrison *et al.* (1991).

Coral species	1974*	1991**	2003
ACROPORIDAE			
Acropora sp.			x
A. latistella		x	
SIDERASTREIDAE			
Psammocora superficialis		x	x
P. albopicta		x	
DENDROPHYLLIDAE			
Turbinaria mesenterina			x
T. peltata	x	x	
MUSSIDAE			
Acanthastrea bowerbanki		x	
A. echinata		x	x
A. lordhowensis		x	x
Micromussa amakusensis		x	
FAVIIDAE			
Barabattoia amicorum			x
Cyphastrea serailia	x	x	x
Favia danae		x	
F. maritima		x	x
F. pallida		x	
F. speciosa-favus	x	x	x
Favites abdita	x	x	
F. halicora	x		
F. flexuosa		x	
Goniastrea aspera		x	x
G. australensis		x	x
Plesiastrea versipora		x	x
PORITIDAE			
Goniopora djiboutiensis		x	x
G. columna			x
G. lobata	x	x	x
G. minor		x	x
G. stokesi		x	
G. somaliensis			x
G. stutchburyi		x	x
Total no. of species	6	23	19

area. In order to record all the coral species present at each site, haphazard searches were conducted for about an hour. Coral species lists were also compiled for Goat Island and Polka Point using haphazard searches, but coral cover was not quantified at these sites. Due to the difficulty in distinguishing between *Favia speciosa* from *Favia favus* in the field, these two species were grouped together for analysis as *Favia speciosa-favus*. For corals requiring taxonomic verification, skeleton samples were collected and identified as described above, with additional species information from Wallace (1999) & Veron (2000).

SPECIES RICHNESS, EVENNESS AND DIVERSITY INDICES

Species richness was calculated as the total number of species recorded within the quadrats along each transect. Brillouin's evenness (BE) and diversity index (HB) (Magurran 2004) were calculated in order to compare the 1991 and 2002 survey data. These indices were calculated on the number of individual colonies.

Brillouin diversity was calculated using:

$$HB = \frac{\ln N! - \sum \ln n_i!}{N}$$

Where n_i = the number of colonies of each species, and N = the total number of corals in the transect.

Brillouin evenness was calculated using:

$$BE = HB/HB_{max}$$

HB_{max} is given by:

$$HB_{max} = 1 / N \ln \frac{N!}{\{[N/S]!\}^{S-r}\ \{([N/S]+1)!\}^{r}}$$

where S = the total number of species, N = the total number of corals, [N/S] = the integer of N/S, and r = N-S[N/S]. '!' = factorial.

To test for differences in species richness, diversity and evenness among locations and between the two time periods, a non-parametric Wilcoxon/Kruskal-Wallis test was performed using JMP IN version 4.0.4.

RESULTS

PERCENT CORAL COVER

Coral cover showed a general increase from west to east within the bay. Mean coral cover ranged from 0.8% at Green Island west, to 42% at Myora Reef, recorded in 1991 and 1994, respectively (Table 1). There was a trend of

Table 7. List of scleractinian coral species observed at Goat Island and Polka Point, in Moreton Bay, during surveys. * = Lovell (1975, 1989), ** = Maguire (1994).

Coral species	Goat Is. 1974, 1989*	Goat Is. 1994**	Goat Is. 2003	Polka Pt. 2002
ACROPORIDAE				
Acropora sp.		x		x
A. digitifera	x		x	
A. divaricata			x	
A. gemmifera			x	
A. glauca			x	
A. loripes			x	
A. lutkeni			x	
A. solitaryensis			x	
Astreopora listeri			x	
SIDERASTREIDAE				
Psammocora profundacella			x	
P. contigua	x			
DENDROPHYLLIDAE				
Turbinaria sp.		x		
T. frondens			x	
T. mesenterina				x
T. peltata	x		x	x
T. patula			x	
T. radicalis			x	
MUSSIDAE				
Acanthastrea sp.		x		
A. bowerbanki			x	
A. echinata			x	
A. hemprichii			x	
A. hillae			x	
A. lordhowensis			x	
FAVIIDAE				
Cyphastrea sp.		x		
C. serailia	x			x
Favia sp.		x		
F. danae			x	x
F. maritima			x	x
F. rotumana				x
F. speciosa-favus	x		x	x
Favites sp.		x		
F. abdita	x			
F. halicora	x			
Goniastrea sp.		x		
G. aspera			x	x

Table 7 continued ...

Coral species	Goat Is. 1974, 1989*	Goat Is. 1994**	Goat Is. 2003	Polka Pt. 2002
Goniastrea australensis			x	
G. palauensis			x	
Montastrea curta			x	
Plesiastrea sp.		x		
P. versipora	x			
Platygyra lamellina	x			
PORITIDAE				
Goniopora djibutiensis			x	
G. lobata	x		x	
G. minor			x	
G. stokesi			x	
Total no. of species	10	8	29	9

increasing mean coral cover between the 1991–1994 and the 2002–2003 surveys at all locations (between 1 and 10%), except at the northern sites of Peel Island were mean coral cover decreased from 18% to 10%.

CORAL SPECIES AND SPECIES RICHNESS

During the 1991–1994 surveys, the total number of coral species recorded was 46, belonging to 19 genera from 8 families (Tables 2–7). During the 2002–2003 surveys the total number of coral species recorded was 51 belonging to 17 genera from 8 families. A combined total of 63 species were recorded during these combined survey periods, belonging to 21 genera from 10 families. *Favia speciosa-favus*, *Favia maritima* and *Goniastrea aspera* were the only species common at all locations. At Myora Reef, six species were present that were not observed elsewhere inside the bay: *Acropora hyacinthus*, *A. latistella*, *A. loripes*, *A. valida*, *A. verweyi*, and *Leptastrea purpurea*. *Astreopora listeri* and *Goniastrea palauensis* were only recorded at Goat Island. *Acropora gemmifera* was only observed at Goat Island. A total of 23 species were recorded in Moreton Bay that have not been recorded at Flinders Reef (Veron 1993): *Acropora loripes*, *Barabattoia amicorum*, *Blastomussa wellsi*, *Cycloseris cyclolites*, *Favia danae*, *F. lizardensis*, *F. matthaii*, *F. maxima*, *F. rotumana*, *F. stelligera*, *Favites halicora*, *F. complanata*, *Goniastrea aspera*, *G. palauensis*, *Goniopora columna*, *G. minor*, *G. stokesi*, *G. tenuidens*, *Leptastrea purpurea*, *Micromussa amakusensis*, *Oulophyllia crispa*, *Psammocora superficialis* and *P. albopicta* (Tables 2–7).

Coral species richness, evenness and diversity, recorded within the quadrats along the transects, all increased in more recent surveys compared with the study by Lovell (1975) (Table 8). The lowest species richness (5 species) was recorded at Mud Island and Empire Point during the 2002–2003 surveys. The highest species richness was recorded at the eastern side of Green Island (28 species) during the 1991 survey, but only 16 species were recorded at this site during the 2002 survey. Evenness was similar between the two survey periods at all locations except for Wellington Point, which was higher during the 2003 survey period (from 0.3–0.9). The lowest evenness was recorded at Wellington Point (0.3) and was relatively high at all other locations (0.6–0.9). The lowest coral species diversity was recorded at Mud Island and Myora Reef (0.5) during the 2002–2003 surveys. During both 1991 and 2002 survey periods, the highest coral species diversity was recorded at Peel Island south east (1.8). Species richness, diversity and evenness were all not significantly different between the survey periods in 1991–1994 and 2002–2003 (Wilkoxon/Kruskal-Wallis test: $p > 0.7$, $p > 0.5$ and $p > 0.1$, respectively).

DISCUSSION

The results of surveys in Moreton Bay over the past 16 years have shown a general increase in mean percentage coral cover since the study by Lovell (1975) and after the 1974 flood (Lovell 1989) at all sites, except at the eastern reef of Green Island. An increase in coral species rich-

Table 8. Coral species richness (total number of species found inside the quadrats along the transects). Brillouin diversity and evenness indices (mean ± standard deviation) calculated for the scleractinian corals of Moreton Bay by Lovell (1975) (*), Harrison *et al.* (1991) (**) and in 2002-2003 (***). - = no data.

Location	Richness	Diversity	Evenness
Mud Is SW*	3	-	-
Mud Is SW***	5	0.5 ± 0.3	0.8 ± 0.5
Green Is E*	14	0.3	0.4
Green Is E**	28	1 ± 0.5	0.8 ± 0.2
Green Is E***	16	1.2 ± 0.3	0.9 ± 0.1
Wellington Pt*	5	0.04	0.1
Wellington Pt**	24	0.7 ± 0.9	0.3 ± 0.5
Wellington Pt***	12	1.1 ± 0.2	0.9 ± 0.02
Empire Pt*	5	-	-
Empire Pt***	5	0.6 ± 0.4	0.6 ± 0.3
Peel Is SE*	5	0.3	0.5
Peel Is SE**	24	2.1	0.9 ± 0.04
Peel Is SE***	18	1.8 ± 0.3	0.8
Peel Is N*	9	0.2	0.2
Peel Is N**	21	1.6	0.7
Peel Is N***	19	1.3 ± 0.2	0.6 ± 0.1
Myora Reef*	5	-	-
Myora Reef**	11	-	-
Myora Reef***	11	0.5 ± 0.3	0.5 ± 0.4

ness was recorded at all sites. Myora Reef had the highest mean percentage coral cover but relatively low coral species richness, although a number of *Acropora* species were present only at that site.

CHANGES IN SCLERACTINIAN CORAL COMMUNITIES OVER TIME

The survey results showed some fluctuations in mean percentage coral cover over time. For example, there was a decrease in mean coral cover in 2002 at the northern reef of Peel Island since the study by Maguire (1994), and an increase at the western reef of Peel Island in 2002 (EHMP 2004) since the study by Maguire (1994). A considerable increase in mean coral cover was also recorded at St. Helena Island, Coochiemudlo Island, the western reef of Green and Peel Islands (EHMP 2004), and at the north east reef of Peel Island (Maguire 1994) since the study by Lovell (1975) and after the 1974 flood (Lovell 1989). The increase in live coral cover and coral species richness recorded at most sites since the 1974 flood indicate that these coral communities are recovering. Variations in mean coral cover recorded at some sites during recent surveys may also reflect spatial patchiness and slight differences in the locations surveyed at each site. The mean percentage coral cover at S-SE Mud Island was low (1%) but similar to the pre-flood situation at SW Mud Island (Table 1). This was unexpected because at this location coral dredging occurred between 1937 and 1995 (Allingham & Neil 1995). This indicates either that some remnant corals survived the dredging, or that coral settlement and growth has been relatively high since dredging ceased. These communities have a very patchy distribution and although the variation in percentage coral cover may be due to differences in the locations sampled during each survey period, they indicate that coral cover is presently very low at Mud Island.

Under less disturbed conditions, the mean percentage coral cover has increased substantially at some sites in Moreton Bay (e.g. St. Helena Island, the western side of Green Island, the north-east side of Peel Island and Myora Reef, Table 1). The increase in coral cover is likely to result from growth of recruits at sites where coral mortality was very high following the 1974 flood, and at some sites from growth of surviving corals and more recent recruits. Lovell (1975) reports growth rates of *Favia speciosa* of approx. 0.5 cm in diameter per year. Roberts & Harriott (2003) reported similar growth rates for *Goniastrea australensis*, whereas *Cyphastrea serailia* grew faster and *Psammocora superficialis* grew more slowly. According to the measurements by Lovell (1975) coral colonies of 10 cm in diameter can grow 4 cm in eight years, which represents a 30% increase in size. However, distance from the mainland is likely to affect coral growth due to the gradient in water quality and environmental conditions (Johnson & Neil 1998b; Dennison & Abal 1999). Colony inversion can also substantially affect coral growth. Roberts (2000) observed frequent changes in growth trajectory and interruptions to colony growth caused by partial coral mortality. This process occurs typically in environments where scleractinian corals grow on loose substratum, such as loose coral rubble that dominates most reefs in Moreton Bay, and colonies can easily been turned over by waves resulting in partial coral death and reduced growth. Boat anchors can also cause colony inversion, and may fragment corals. The presence or absence of suitable substratum for coral larvae (Harrison & Wallace 1990) is also likely to affect coral recruitment patterns within the bay (Harrison *et al*. 1998).

Since the 1974 flood, other stressors have acted upon these coral communities at different scales and have contributed to the different patterns of coral recovery or decline within the bay. These include the 1996 flood that caused increased sedimentation and pollutants within some parts of Moreton Bay. The adjacent city of Brisbane has one of the fastest growing populations in Australia (Skinner *et al*. 1998), and human activities such as land clearing and farming strongly interfere with Moreton Bay biota. Increased sedimentation, turbidity, nutrients and pollutants due to human activity have been long recognised as being detrimental to corals and affect their growth, survival and reproduction (Rogers 1990; Ward & Harrison 1997; Harrison & Ward 2001; Cruz-Pi ón *et al*. 2003; Sanders & Baron-Szabo 2005; Harrison & Booth 2007).

Due to the shallow nature of Moreton Bay, both extreme low and high temperatures occur occasionally (Johnson & Neill 1998b). Conspicuous coral bleaching has been observed in Moreton Bay in the summer of 1998 (I. Tibbetts pers. comm.) and winter and summer bleaching was observed during 2002 affecting some coral colonies at Green Island, Peel Island and Empire Point. This indicates that the minimum and maximum thermal tolerance limits for these corals are sometimes exceeded (Hoegh-Guldberg & Jones 1999).

SPECIES RICHNESS, EVENNESS AND DIVERSITY INDICES

Recent surveys have revealed a much higher number of scleractinian coral species compared to earlier studies by Wells (1955) and Lovell (1975, 1989). This may be partly due to recruitment by coral species new to Moreton Bay, but also due to improvements in taxonomic knowledge as new scleractinian species have been recognized (Harrison *et al*. 1991; Wallace 1999; Veron 2000; Benzoni 2006). A re-examination of the coral reference collection at the Queensland Museum revealed that it contained a number of species not recognised at the time of the publication by Lovell (1975) (Wallace *et al*., in prep.), and Benzoni (2006) described a new species, *P. albopicta*, which was collected at Wellington Point in 1991. Furthermore, rare species found at the limits of their distribution, can rapidly appear and disappear over time (Veron 1979; Harriott *et al*. 1995; Harrison & Booth 2007), and communities from locations where conditions are marginal are more easily subject to changes (Dollar & Tribble 1993; Glynn 2000). Bellwood & Hughes (2001) concluded that Acroporidae tend to become less common at sites with low species richness, whereas Faviidae become more common. The coral communities in Moreton Bay also reflect these trends as they have relatively low species richness and few Acroporidae, and tend to be dominated by Faviidae.

Evenness is inversely related to dominance, therefore maximum evenness (= 1) means that all species within an assemblage are equally abundant and that no species dominate (Magurran 2004). Evenness was relatively high at many locations suggesting that these coral communities are not dominated by any one species. In contrast, evenness was low at some sites where *Favia speciosa-favus* colonies were dominant (Table 8). During the 2002–2003 survey, 275 specimens of *F. speciosa-favus* were recorded from a total of 749 coral specimens (Fellegara, in prep.). Evenness was relatively low at Wellington Point in 1991 (Harrison *et al*. 1991) but showed a remarkable increase in 2003. This may be a consequence of a slight decrease in the number of species present (only 4) and an increase in mean percentage coral cover (from 1.3–2.8%) between the 1991 and the 2002 surveys. The main coral community at Myora Reef had an average diversity and evenness of 0.5. Although this community was dominated by *Acropora digitifera*, a number of other species represented by small colonies contributed to its higher diversity.

Most of the species found in Moreton Bay have a wide biogeographic distribution, such as *Plesiastrea versipora* and *Turbinaria frondens*, which occur as far south as Lord Howe Island and in some case as far south as southern

Australia (Veron 1993; Harriott *et al.* 1995; Veron 2000). A few of these species, such as *Acanthastrea hemprichii* and *Barabattoia amicorum*, are at the southern limit of their distribution (Veron 1993, 2000). *Pocillopora damicornis* occurs in a wide range of reef habitats and sometimes in mangrove wetlands (Veron 2000). However, although relatively common at Amity Rockwall and outside Moreton Bay at Flat and Shag Rocks (McMahon *et al.* 2002; Ford *et al.* 2003), only two live specimens of *Pocillopora damicornis* have been recorded within the Bay at Myora Reef and Peel Island, but none have been observed further inside the Bay during any surveys. A recent study on the identity of *Symbiodinium* dinoflagellate microalgae associated with the scleractinian corals and other symbiotic organisms present inside and outside Moreton Bay, showed that *P. damicornis* had different symbiont populations to all the other taxa examined inside Moreton Bay (Fellegara 2008). The *Symbiodinium* population found among the symbiotic organisms inside Moreton Bay was consistent across all organisms and showed very low diversity, which suggests that this specific *Symbiodinium* population is adapted to the subtropical and often turbid conditions in the Bay.

The *Acropora* species recorded in Moreton Bay have also a wide biogeographic distribution range, although *Acropora glauca* and *A. solitaryensis* are more commonly recorded at subtropical reefs south of the GBR (Wallace 1999). The *Acropora digitifera*-dominated community at Myora Reef supports a diversity of *Acropora* species that are not present further inside the Bay (Harrison *et al.* 1998). This may be due to the fact that Myora Reef receives clearer oceanic water twice a day, and it is therefore warmer in winter (Steele & Kuhl 1993; Harrison *et al.* 1995, 1998) and cooler in summer (EHMP 2004), compared to most other areas in Moreton Bay. This flux of oceanic water can also reach Peel Island within the bay and may have favoured the growth of some large colonies of *Acropora* cf. *solitaryensis*, up to approx. 2.5 m in diameter, on the submerged reefs along its northern side.

MANAGEMENT ISSUES

Most sites surveyed within Moreton Bay showed an increase in mean percentage coral cover, species richness, evenness and diversity since the 1974 flood. Some sites had considerably higher coral cover whereas at the eastern reefs of Green Island, coral cover was considerably lower than the pre-flood conditions. Green Island east is used both for commercial and recreational fishing; activities that increase pressure on this environment. Eastern Green Island used to have relatively high percentage of coral cover (34.2%, Lovell 1989) but the community has not recovered from the 1974 flood, hence protection of this site should be considered. This site is also important within Moreton Bay because of the presence of large *Psammocora superficialis* colonies (Harrison *et al.* 1991) that have been dated at over 200 years old (Roberts & Harriott 2003). These colonies create habitat complexity that favours the presence of commercial species, such as lobsters *Palinurus* sp., and reef fish species, such as the whiptail *Pentapodus setosus*, the knight fish *Cleidopus gloriamaris* and the moses perch *Lutjanus russelli*, which increase the biodiversity of Moreton Bay.

A higher level of protection of the reefs of SE Peel Island is recommended to conserve this area, as it has the highest coral richness and diversity recorded within Moreton Bay. Goat Island had a similar number of coral species to Peel Island and one species, *Astreopora listeri*, which has not been recorded elsewhere in Moreton Bay, although it has been reported at Flinders Reef (Veron 1993). A relatively large one-metre diameter colony of *Acropora gemmifera* was also observed at Goat Island. The reefs around Goat Island require a further and more detailed investigation to quantify the status of the coral community, the full coral species richness present, and to understand the effects of human activities, such as anchor damage from recreational fishing, and continuously resuspended sediment from increased ferry traffic near the island.

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